AN EVALUATION OF THE ILLUMINANT-STABLE COLOR VISION TEST

APPROVED:

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Dean of the Graduate School

AN EVALUATION OF THE ILLUMINANT-STABLE COLOR VISION TEST

DISSERTATION

Presented to the Faculty of the Graduate School of
The University of Texas in Partial Fulfillment
of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

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PREFACE

Among the characteristics of our time are the increasingly significant functions assumed by color. Air, water, and land transportation systems utilize colored lights for their traffic signals. In electricity and radio, wires are coded in color. In scientific work certain cues can be got only through color and changes in color.

From this it follows that pilots and navigators of ships and of planes must have keen color discrimination in order to properly safeguard human lives and property. The same is true of railroad engineers and conductors. Persons in industry, architecture, chemistry, geology, and medicine, to mention only a few, require good chromatic vision to perform their jobs properly.

Aside from the risk of the employer in having a color defective in a position that requires color vision, there are other considerations. It may be a waste of time and money for an employer to train a person for a job only to find that he cannot fill it because of a visual inadequacy. Apparently, most deficients do not know that they are color blind until they are subjected to a test. It is not fair to let them build hopes of being artists, for example, to let them spend years preparing for this occupation and then at the critical time to let them know that they have visual disqualifications. This leads to frustration, frustration that often takes years to overcome.

Many of the subjects participating in this research complained about the handicap of not having keen color vision. A large

percentage of these are students majoring in architecture, chemistry, geology, or electrical engineering. Nearly all of these said they did not realize they were color defective until they had either taken some test or begun having trouble in their course work where the discrimination of color was essential.

I am most grateful to Dr. Ellis Freeman, Visiting Professor of Psychology at The University of Texas, for the problem, his assistance, his interest, and the use of his own personal apparatus.

I am deeply indebted also to my teachers in psychometrics - Dr. D. F. Votaw of Southwestern Texas State Teachers College, Dr. C. T. Gray of The University of Texas, and Dr. H. T. Manuel of The University of Texas.

Appreciation must also be expressed to the 200 color blind and normal subjects who volunteered and gave generously of their time. Without these, this research could not have been conducted.

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The University of Texas
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CHAPTER I

INTRODUCTION

Methods of Testing Color Vision

There are three major techniques of testing color vision. The first method employs a color-mixing apparatus, such as an anomaloscope or a colorimeter. The second method utilizes colored lanterns. The third method makes use of colored yarns, or colored papers.

Method Utilizing Color-Mixing Apparatus

The method which utilizes a color-mixing apparatus makes use of a bipartite field to which spectral or filtered lights are delivered. For instance, a given yellow may be placed in the upper half of the field. This can be matched in the lower half of the field by the mixture of certain quantities of red and green (Rayleigh's equation). A person with normal color vision has little or no difficulty making this match, whereas dichromats and anomalous trichromats not only take longer than the normal to make the match but their Rayleigh equation deviates considerably from the normal. Also, if they repeat the task of matching the same hue, their second Rayleigh equation deviates from their first much more than does that of the normal.

The equipment that uses spectral light, such as Nagel's anomaloscope or Abney's colorimeter, has an advantage over that using

colored glass filters, such as Hering's color-mixing apparatus. It is relatively easy for one with normal color vision to match spectral yellow with spectral red and green, whereas it is relatively difficult for him to match some yellow filtered light with red and green filtered lights. By using spectral lights the colors are pure and one can use the exact colors he wants, whereas a filter is always a mixture of several colors or a rough approximation, at best.

Several disadvantages are found in using color-mixing apparatus. First, it takes a well-trained examiner to administer the test. Second, the apparatus is costly and delicate. The third factor is the long time needed to make a match. Lastly, the equipment involves difficulty in transporting and setting up. It can easily be seen that this method does not lend itself to rapid testing of large numbers of individuals.

Method Utilizing Colored Lanterns

Among the colored lantern tests, Edridge-Green's Lantern Test deserves special mention. Here an attempt was made to simulate the actual conditions found on a railway system. Edridge-Green constructed a lantern which has a source of light and several colored glasses, as well as three modifying glasses. The latter three were chosen to represent respectively, a slight fog, a dense fog, and rain. Under these various conditions, the candidate was asked to name the colors of lamps similar to those used on the railways. The modifying glasses are not supposed to affect the color judgment of a normal person, but are supposed to reveal a color vision defect.

Several criticisms can be leveled against this test. Since the individual has to name the color of lamps similar to those on the railroad, he has to identify a color that he had seen with one that he is seeing. When he names the color, there is no way of knowing what he does see. This will result in the failure of some with good color vision and the passing of others with poor color vision. Other disadvantages are that only a trained examiner can administer the test and that the test does not lend itself to the rapid examination of large numbers. Moreover, the stimuli are so coarse and mixed that detection of only the grossest deficiency is likely.

Method Utilizing Colored Yarns Or Colored Papers

The yarn and colored paper tests fall into three general classes, namely, color naming tests, color matching tests, and tests which involve the discrimination of figures from crazed patterns.[1]

Color-Naming Tests

In the color naming tests the subject is required to select from colored papers or wools the colors indicated by name. This type of test exemplified in the course of the Holmgren yarn and Nagel card tests, has little or no value since many people who are color defective

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[1] Colored dots or disks are placed at random on a white background.

will correctly select all or most of the "right" colors, whereas some normals will err in the selection of the "right" colors. The function of color vision tests is primarily to test the chromatic discrimination of an individual. Ability to name or select particular hues is not necessarily correlated with such discrimination.

Color-Matching Tests

The color matching tests have also proven to be inadequate. The Holmgren test is a typical example of this category. In such a test the subject is asked to select from a number of colored wool yarns all those that match a certain sample in hue. Confusion arises as to saturation, brightness, and hue among those who are not well acquainted with the handling of colors. This type of test is not discriminating enough. Some normals fail the test while some color blinds pass it when a critical score is used.

Polychromatic Printed (Crazed Pattern) Tests

Tests which involve the discrimination of figures from crazed patterns are the most useful. These are typified by the Stilling and the Ishihara. These tests when properly designed are very effective, convenient, and practical, but they do require the standard illuminant for which they have been designed. In the typical plate are found hues from widely separated parts of the spectrum. It is obvious that a non-standard illuminant of lower color temperature than the standard illuminant will favor the prominence in perception of colors at the longer

end of the spectrum. On the other hand, a non-standard illuminant of higher color temperature than the standard illuminant will favor the prominence in perception of the colors lying in the shorter region of the spectrum. Hence, such errors as reported at the United States Submarine Base.

> Routine testing of the color vision of applicants for Submarine Service by the Medical Research Laboratory, New London, revealed that previous physical examinations had been only 50% effective in screening out color defectives by the criterion of the test itself.[2]

The non-standard illuminant is "the largest contributing factor," and is the rule rather than the exception in the Navy.[3]

Color temperatures were taken with the Eastman Color Temperature Meter at irregular intervals throughout a period of forty-eight hours in actual Army and Navy testing rooms and in other typical testing rooms. The results are plotted in Figure I. These color temperatures range from 2,600°K to 10,500°K. The data show that the lower color temperatures are much more frequent than those approximating illuminant C (6,500°K), the illuminant for which polychromatic printed tests have been designed.

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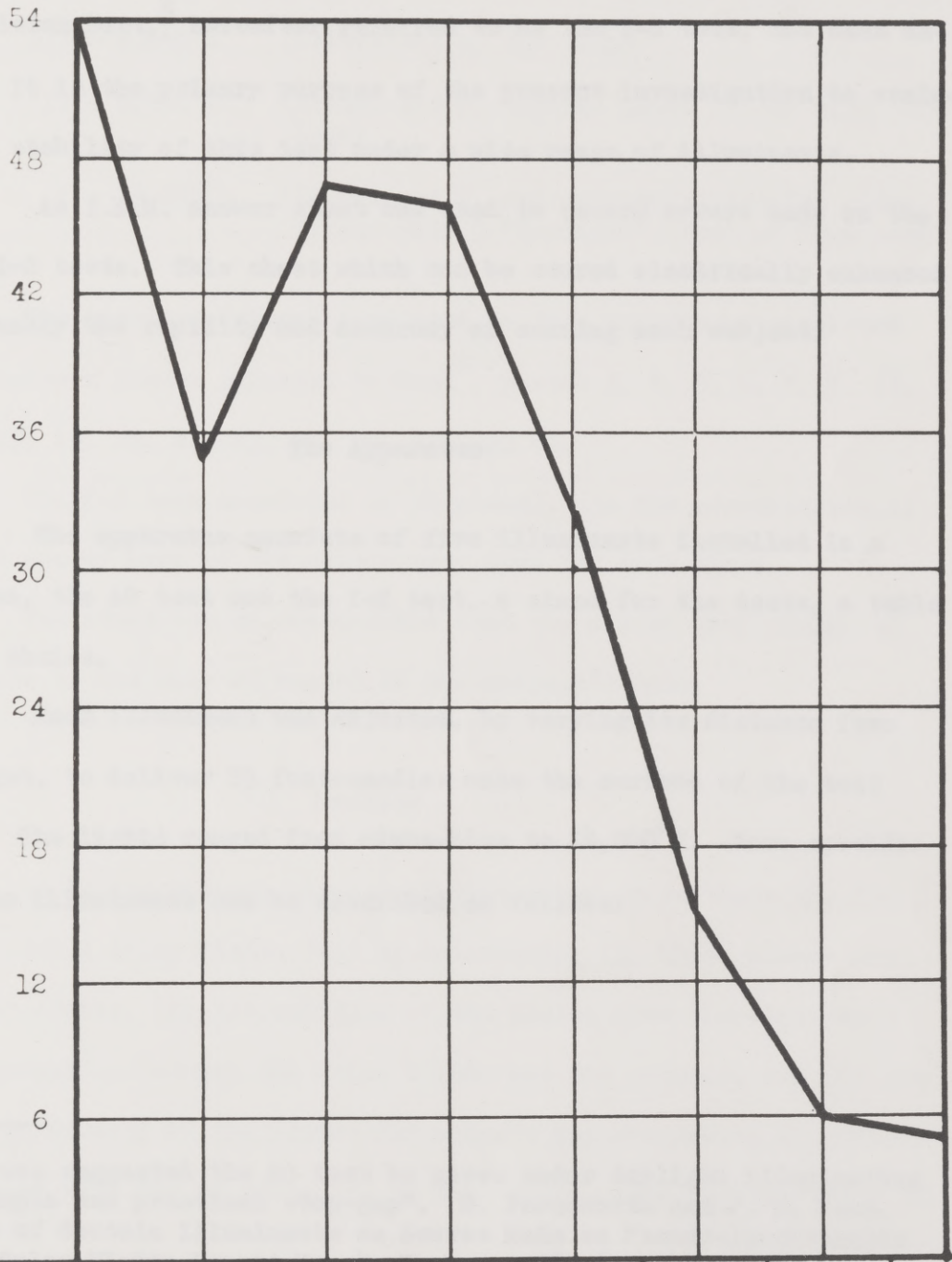
[2] D. Farnsworth and J. D. Reed, "A Survey of Methods Used in Administering Pseudo-Isochromatic Test Plates for Color Vision," Color Vision Report No. 3, Bu Med x-260 (Av-148-C), 6 Nov., 1943: p. 1.

[3] Ibid., p. 6.

FIGURE I

FREQUENCY DISTRIBUTION OF COLOR TEMPERATURES



COLOR TEMPERATURE	2600-3550	3600-4550	4600-5550	5600-6550	6600-7550	7600-8550	8600-9550	9600-10500
FREQUENCY	54	35	47	46	33	15	6	5

Since it is impractical for the polychromatic test to be given under "standard illuminating" conditions,[4] an Illuminant-Stable Color Vision Test,[5] hereafter referred to as the I-S test, has been devised. It is the primary purpose of the present investigation to evaluate the stability of this test under a wide range of illuminants.

An I.B.M. answer sheet was used to record errors made on the AO and I-S tests. This sheet which can be scored electrically enhanced considerably the rapidity and accuracy of scoring each subject.

The Apparatus

The apparatus consists of five illuminants installed in a dark room, the AO test and the I-S test, a stand for the tests, a table and two chairs.

Each illuminant was adjusted, by varying its distance from the target, to deliver 25 foot-candles onto the surface of the test plates. The lights ranged from minus-blue to 14,000°K. More specifically the illuminants can be described as follows:

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[4] It was suggested the AO test be given under daylight illumination as "a simple and practical stop-gap". D. Farnsworth and J. D. Reed, "Effects of Certain Illuminants on Scores Made on Pseudo-Isochromatic Tests", Color Vision Report No. 4, Bu Med x-261 (Av-149-C), 22 Nov., 1943: p. 5.

[5] Ellis Freeman, "An Illuminant-Stable Color Vision Test, I," Journal of The Optical Society of America, Vol. 38, No. 6, June, 1948.

Illuminant

I - minus-blue (Wratten Filter #16 with 75w lamp)

II - 2,000°K (500w lamp at 60 volts)

III - 2,850°K (Illuminant A, 75w lamp)

IV - 6,500°K (Illuminant C, special glass filter with 500w lamp)

V - 14,000°K (Illuminant Z, approximately; special glass filter with 3 "daylight" lamps of 200w each).

The American Optical test used in this experiment consisted of the eighteen plates selected by Rand[6], plates 3, 4, 5, 6, 8, 9, 12, 13, 16, 17, 19, 20, 21, 23, 27, 29, 41, and 42.

The I-S test consisted of 34 plates. In the construction of this test two or more of six colors were used for each plate.

The stand was so constructed that the plates were always at right angle to the line of regard of the subject's eyes.

Problem

It is the primary purpose of this study to evaluate the Illuminant-Stable Color Vision Test by determining (1) which plates are illuminant-stable, (2) the validity of the plates from the standpoint of discriminating between the color blinds and the normals, and (3) the relative difficulty of the plates for normals and abnormals; to compare the I-S test with the AO test; and to make suggestions for improving the I-S test.

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[6] L. H. Hardy, G. Rand, and M. Rittler, "A Screening Test for Defective Red-Green Vision." Journal of The Optical Society of America, Vol. 36, No. 10, October, 1946, p. 613.

Procedure

Five groups of red-green color blinds and five groups of normals were used in this study. Each group consisted of twenty subjects. In all, one hundred color blinds and one hundred normals were used. All were volunteer subjects attending The University of Texas, except three, who were from Southwestern University. All the color blinds were males, whereas nearly two thirds of the normals were females. Color blinds were those classified as color blind in the armed forces during the war.

The normals were classified as such in accordance with the standards set up by Hardy, Rand and Rittler.[7]

Each subject was first presented each of the eighteen plates of the AO test, then each of the thirty-four plates of the I-S test under each of the five illuminants, after having been instructed to "report what number you see and not what number you think should be there." After being tested with both tests, under the five illuminants, each subject was retested under his first illuminant. The order of the illuminants was determined by the group each subject was in.

Those in Group I-C (color blinds in Group I) and those in Group I-N (normals in Group I) were given the tests under Illuminants I, IV, III, II and V successively and then retested under the first illuminant.

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[7] Ibid., p. 613

The order of Illuminants for Groups II-C and II-N was II, III, IV, V, and I; for Groups III-C and III-N, III, II, V, I, and IV; for Groups IV-C and IV-N, IV, V, I, II, and III; and for Groups V-C and V-N, V, I, II, IV and III. Each subject was retested under the illuminant under which he began. These groups were tested under the particular sequence of illuminants in order that the data could be combined in such a way that the plates would have an equal chance under each illuminant, as far as practice effect is concerned.

For scoring, an incorrect response on any one or both digits of a two-digit plate was scored as a single error. In the case of the AO test, if the subject gave two different responses for one plate, he was asked to tell the experimenter which digit or digits were clearest to him and scored accordingly. This scoring was applied to AO plates with unambiguous as well as ambiguous numerals.

Data on the distribution of error scores under the various illuminants was secured from the answer sheets. The tables show, for instance, the error scores for each individual under each of the five illuminants for the AO and the I-S tests.

The main part of the problem dealt with the selection of plates on the I-S test which are consistent throughout under the various illuminating conditions. In order to do this, tabulations were made of the number of subjects of the 100 color blinds and of the 100 normals missing each plate under each illuminant.

It soon became obvious that some plates were consistent for color blinds under the various illuminants or for the normals. However, this would not be enough. A plate must be consistent under the various

illuminants for both the color blinds and the normals. Therefore, a measure of illuminant-stability of each plate had to be used. It is logical that the smaller the difference under the various illuminants, the better the plate would be for this purpose.

After the "good" plates were selected on this basis, it was only proper to try out these plates under the actual conditions of illumination. This was done by statistical computations of the 17 "good" plates under the new range of illuminants, from 2,425°K to 10,250°K.

Statistical computations were also made on the AO test so that direct comparisons could be made between the AO and the I-S tests.

Comparisons were made as to the differences existing because of the various illuminating conditions. Comparisons were also made of the test-retest differences on the two tests.

The diagnostic power of each plate was another important consideration. A useful index of validity for a test item or a test plate is some type of correlation coefficient. The biserial r, while highly accurate, is laborious to compute.[8] Fortunately this can be approximated from tables.[9]

For the last part of the problem each plate was ranked according to its order of difficulty.

Next, comparisons were made regarding the distributions and overlapping of scores of the color blinds and the normals on the AO test and on the I-S test.

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[8] J. P. Guilford, Fundamentals Statistics in Psychology and Education, p. 295.

[9] F. B. Davis, Item-Analysis Data. Tables from this pamphlet were used.

CHAPTER II

RESULTS OF THE INVESTIGATION

The distribution of error scores for each subject under each illuminant on the AO test is shown in Tables I through X. The order of illuminant and the test-retest differences are also shown. For instance, in Table I, "Order" 1 indicates that the test was given first under Illuminant I; second, under Illuminant IV; third, under Illuminant III; fourth, under Illuminant II; fifth, under Illuminant V; and the retest, (R)[10] under Illuminant I. The test-retest difference (1-R) for each subject is recorded in the last column throughout the first ten tables.

Tables I through V are concerned with the error scores of the five color blind groups, whereas Tables VI through X are concerned with the error scores of the five normal groups.

[10]The retest is always given under the Illuminant first in "Order".

TABLE I

AO TEST SCORES OF 20 SUBJECTS IN GROUP I-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	I	II	III	IV	V	I
	ORDER						
Subject	1	R	4	3	2	5	1-R
1	9	9	10	9	14	16	
2	8	6	8	12	12	12	2
3	13	13	16	18	16	14	
4	9	9	7	6	14	16	
5	9	9	9	9	14	14	
6	13	14	16	16	14	15	-1
7	9	11	8	8	12	15	-2
8	9	8	8	10	12	12	1
9	8	8	8	7	13	12	
10	7	10	14	14	12	14	-3
11	12	13	16	16	15	16	-1
12	10	9	5	6	11	11	1
13	11	11	9	11	16	18	
14	10	7	9	9	16	15	3
15	12	12	17	16	16	16	
16	6	4	5	5	8	10	2
17	8	9	8	8	16	16	-1
18	12	9	6	8	14	14	3
19	11	11	15	14	14	11	
20	4	4	7	10	11	10	

Note: A blank space indicates a zero in all tables.

TABLE II

AO TEST SCORES OF 20 SUBJECTS IN GROUP II-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	II	III	IV	V	II
	ORDER						
Subject	5	1	R	2	3	4	1-R
1	11	9	12	11	15	16	-3
2	4	2	3	4	8	11	-1
3	2	2	1		2	4	1
4	9	10	10	10	11	11	
5	2	1	1		5	8	
6	9	8	7	10	14	14	1
7	5	7	5	7	11	11	2
8	7	14	9	13	13	13	5
9	3	4	3	9	9	8	1
10	11	15	16	16	15	15	-1
11	5	7	4	8	10	12	3
12	10	10	8	12	16	14	2
13	4	6	2	4	12	11	4
14	5	3	3	4	6	10	
15	12	15	16	16	16	15	-1
16	12	16	15	13	13	12	1
17	7	7	6	6	10	9	1
18	10	15	13	15	14	11	2
19	11	12	13	13	14	17	-1
20	9	13	12	12	15	13	1

TABLE III

AO TEST SCORES OF 20 SUBJECTS IN GROUP III-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	III	IV	V	III
	ORDER						
Subject	4	2	1	R	5	3	1-R
1	8	11	12	13	17	17	-1
2	7	6	9	8	10	13	1
3	4	7	4	6	4	7	-2
4	12	16	16	16	14	14	
5	11	16	16	15	16	14	1
6	12	15	16	14	15	16	2
7	11	9	11	9	15	16	2
8	8	9	10	7	14	15	3
9	9	8	10	10	14	15	
10	4	3	4	2	4	7	2
11	8	13	10	11	9	11	-1
12	7	12	11	11	12	13	
13	10	11	11	12	16	16	-1
14	8	7	9	10	16	17	-1
15	5	5	6	6	7	13	
16	5	8	12	10	15	12	2
17	10	10	13	12	16	17	1
18	12	12	13	14	13	15	-1
19	4	3	3	2	9	9	1
20	7	6	7	6	10	13	1

TABLE IV

AO TEST SCORES OF 20 SUBJECTS IN GROUP IV-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	IV	V	IV
	ORDER						
Subject	3	5	4	1	R	2	1-R
1	11	17	17	17	16	15	1
2	10	16	15	13	16	13	-3
3	10	11	13	13	14	14	-1
4	4	4	5	10	9	8	1
5	7	5	6	11	10	9	1
6	13	16	12	14	14	13	
7	4	1	1	11	7	12	4
8	10	12	13	16	15	15	1
9	2	4	7	10	6	10	4
10	8	9	11	12	12	11	
11	4		3	8	6	9	2
12	6	6	6	13	10	11	3
13	4	4	5	10	8	10	2
14	14	16	16	15	15	14	
15	9	6	9	12	15	17	-3
16	13	14	14	15	14	13	1
17	6	6	6	15	16	12	-1
18	6	6	7	15	15	11	
19	10	7	10	15	16	16	-1
20	3	4	5	12	10	11	2

TABLE V

AO TEST SCORES OF 20 SUBJECTS IN GROUP V-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	V	V	V
	ORDER						
Subject	2	3	5	4	1	R	1-R
1	8	7	9	10	13	11	2
2	11	16	17	13	16	16	
3	1	1	2	5	8	10	-2
4	8	15	16	15	15	15	
5	11	8	12	11	14	10	4
6	6	5	6	12	16	15	1
7	12	7	10	14	16	12	4
8	10	10	10	13	16	15	1
9	11	7	7	13	15	13	2
10	11	9	9	14	13	14	-1
11	2	3	3	4	12	8	4
12	9	6	8	14	12	11	1
13	12	16	15	14	14	12	2
14	8	6	6	13	14	11	3
15	8	9	11	16	14	14	
16	15	13	16	16	15	15	
17	10	8	17	16	18	18	
18	8	11	9	13	15	12	3
19	11	9	11	17	17	13	4
20	8	5	9	13	15	15	

TABLE VI

AO TEST SCORES OF 20 SUBJECTS IN GROUP I-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	I	II	III	IV	V	I
	ORDER						
Subject	1	R	4	3	2	5	1-R
1							
2							
3	1						1
4							
5						1	
6							
7						1	
8							
9	2					1	2
10	1	1			2		
11					1		
12					1	2	
13							
14							
15							
16						1	
17							
18						2	
19					1		
20						1	

TABLE VII

AO TEST SCORES OF 20 SUBJECTS IN GROUP II-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	II	III	IV	V	II
	ORDER						
Subject	5	1	R	2	3	4	1-R
1	1						
2						1	
3						2	
4							
5						1	
6					1		
7							
8	1						
9		1			1		1
10						1	
11							
12							
13						1	
14							
15		2				1	2
16		1		1		2	1
17							
18	1						
19							
20						2	

TABLE VIII

AO TEST SCORES OF 20 SUBJECTS IN GROUP III-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	III	IV	V	III
	ORDER						
Subject	4	2	1	R	5	3	1-R
1							
2	1					1	
3	1					2	
4					1	2	
5							
6							
7						1	
8				1			-1
9	1					1	
10						1	
11							
12							
13							
14							
15						1	
16						2	
17	1		1			1	1
18						1	
19							
20	1	1	1	1	3	4	

TABLE IX

AO TEST SCORES OF 20 SUBJECTS IN GROUP IV-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	IV	V	IV
	ORDER						
Subject	3	5	4	1	R	2	1-R
1							
2				1		1	1
3							
4							
5							
6				3		2	3
7				1			1
8	2					2	
9				1			1
10				1		1	1
11							
12	1			1			1
13							
14							
15	2			1		2	1
16				1			1
17							
18				1			1
19							
20				1		2	1

TABLE X

AO TEST SCORES OF 20 SUBJECTS IN GROUP V-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	V	V	V
	ORDER						
Subject	2	3	5	4	1	R	1-R
1					3	3	
2							
3							
4							
5							
6						2	-2
7							
8							
9					1		1
10							
11							
12	1				1		1
13							
14					2		2
15					1	1	
16							
17	3	1	1	3	5	2	3
18					1	1	
19	1			1	2		2
20	1				1	1	

The distribution of error scores for each subject under each illuminant on the 34-Plate I-S test is shown in Tables XI through XX. The order of the illuminants is also indicated. Tables XI through XV are concerned with the five color blind groups, whereas Tables XVI through XX are concerned with the five normal groups. The test-retest differences are not given in these tables since it was not intended that all 34 plates be used. As will be seen later, the test-retest differences have been calculated for the 17 of these plates selected as the final form of the I-S test in this study.

TABLE XI

I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-C

(Under 5 Illuminants)

	ILLUMINANT					
	I	I	II	III	IV	V
	ORDER					
Subject	1	R	4	3	2	5
1	26	26	26	29	34	33
2	28	22	28	31	32	24
3	34	34	34	34	34	33
4	20	18	28	26	34	34
5	26	25	28	29	34	34
6	34	34	34	34	34	34
7	34	34	31	33	34	34
8	25	24	30	32	33	29
9	25	26	30	31	34	34
10	31	30	28	33	30	30
11	34	34	34	33	32	30
12	19	14	17	27	32	31
13	26	29	30	32	34	34
14	34	27	34	33	34	34
15	31	31	33	34	33	33
16	25	21	24	27	31	31
17	23	23	30	30	34	34
18	24	25	26	30	34	34
19	34	34	34	34	34	33
20	25	23	23	23	24	24

TABLE XII

I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-C

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	II	III	IV	V
	ORDER					
Subject	5	1	R	2	3	4
1	29	34	34	34	34	34
2	13	22	17	23	29	31
3	16	20	16	18	21	23
4	30	32	28	33	30	30
5	10	21	9	20	23	28
6	18	26	21	28	33	33
7	25	27	29	29	34	34
8	33	33	33	33	33	33
9	22	24	23	23	25	23
10	33	33	31	32	32	30
11	23	33	27	31	31	29
12	31	34	32	34	34	34
13	12	27	23	26	33	30
14	23	24	21	24	34	32
15	33	33	33	32	32	32
16	32	34	33	33	31	28
17	29	28	29	31	34	34
18	30	34	33	30	29	26
19	31	34	31	34	34	34
20	31	32	32	34	33	32

TABLE XIII

I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-C

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	III	IV	V
	ORDER					
Subject	4	2	1	R	5	3
1	22	25	34	26	32	33
2	19	24	28	24	34	34
3	14	21	24	20	32	33
4	34	34	34	34	34	32
5	33	34	34	34	33	28
6	34	34	34	34	34	34
7	29	30	34	34	34	34
8	28	30	30	29	34	34
9	28	32	34	33	34	34
10	18	20	23	19	27	26
11	30	30	32	28	28	28
12	29	32	33	32	27	29
13	34	33	34	34	34	34
14	25	30	34	27	34	34
15	27	30	33	27	33	34
16	17	24	31	29	32	34
17	31	34	34	34	34	34
18	34	33	34	33	31	29
19	12	20	30	20	27	32
20	21	24	31	26	33	31

TABLE XIV

I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-C

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	IV	IV	V
	ORDER					
Subject	3	5	4	1	R	2
1	34	34	34	34	34	34
2	30	33	31	32	29	31
3	25	32	30	28	26	23
4	20	19	24	28	23	29
5	12	20	19	27	25	25
6	32	30	31	32	32	28
7	21	23	29	29	27	31
8	24	24	34	34	32	34
9	11	10	13	25	21	27
10	24	27	27	28	26	27
11	16	17	18	25	23	32
12	16	17	25	33	31	33
13	19	17	15	25	22	28
14	33	33	33	33	32	33
15	19	29	31	34	34	34
16	33	33	31	33	29	31
17	21	21	21	26	31	33
18	22	18	25	32	31	33
19	28	33	34	34	34	34
20	23	23	24	34	30	32

TABLE XV

I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-C

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	IV	V	V
	ORDER					
Subject	2	3	5	4	1	R
1	25	26	26	33	32	30
2	34	34	34	34	33	34
3	17	16	20	21	30	27
4	33	32	34	27	29	28
5	34	33	33	34	34	34
6	20	19	21	29	31	32
7	20	20	25	28	30	29
8	25	25	27	34	34	34
9	22	24	24	32	31	31
10	17	22	22	27	29	31
11	33	33	33	34	31	31
12	19	25	28	34	32	34
13	33	34	34	34	34	34
14	18	19	20	32	34	30
15	26	31	31	34	34	34
16	34	34	34	34	34	34
17	28	32	34	34	34	34
18	23	24	25	31	34	29
19	26	29	32	34	34	34
20	25	27	30	34	34	34

TABLE XVI

I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-N

(Under 5 Illuminants)

	ILLUMINANT					
	I	I	II	III	IV	V
	ORDER					
Subject	1	R	4	3	2	5
1	6	3	3	3	6	4
2	5	3	3	3	8	6
3	9	5	7	4	3	8
4	2	2	1	2	2	2
5	7	4	7	7	12	10
6		1		3	3	1
7	3	2	1	2	7	4
8	7	4	7	10	15	9
9	15	8	13	11	16	10
10	11	9	9	12	14	13
11	13	8	5	6	12	10
12	3	2	2	1	7	7
13	6	3	3	5	6	6
14	6	7	10	7	10	9
15	3		1	1	1	1
16			2			1
17	2	1	1	2		1
18	6	3	5	5	7	6
19	6	4	6	7	11	8
20	4	4	2	3	6	7

TABLE XVII

I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-N

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	II	III	IV	V
	ORDER					
Subject	5	1	R	2	3	4
1	5	7	2	6	7	6
2	8	14	8	12	10	13
3	6	5	4	7	8	7
4		6	2	1	7	7
5	3	5	2	3	2	2
6	4	4	2	6	8	4
7	1	4	1	4	3	3
8	10	11	7	9	14	14
9	8	17	11	13	8	8
10	9	11	5	9	13	17
11	2	7	1	5	3	5
12	3	10	4	8	5	6
13	2	1	1	2	1	3
14		4				1
15	7	18	6	13	17	17
16	3	11	3	7	10	11
17		1			1	1
18	7	8	5	6	10	11
19	1	6		1	3	5
20	6	9	7	7	10	9

TABLE XVIII

I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-N

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	III	IV	V
	ORDER					
Subject	4	2	1	R	5	3
1	3	5	8	2	3	7
2	8	13	17	10	12	15
3	3	6	5	3	4	5
4	7	11	11	9	8	11
5	6	10	10	8	8	14
6	3	6	4	1	3	11
7	2	7	9	3	7	13
8	3	2	5	2	4	4
9		1	5	2	3	5
10	8	5	6	4	6	7
11			1			2
12	5	3	10	6	10	12
13	1		2	1	1	5
14	1	3	6	1	7	9
15	2	7	4	5	7	11
16	2	2	3	4	2	9
17	8	10	15	9	14	14
18	7	8	8	4	5	14
19	1	4	6	1	2	5
20	6	11	11	6	13	12

TABLE XIX

I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-N

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	IV	IV	V
	ORDER					
Subject	3	5	4	1	R	2
1	9	4	6	14	6	11
2	8	12	10	14	14	18
3	14	11	14	19	13	17
4	4	6	9	10	4	11
5	1	3	2	7	3	7
6	2	1	3	12	4	8
7	7	7	6	16	9	13
8	4	5	6	6	5	9
9	8	9	7	13	4	11
10	9	4	5	20	6	15
11	3	5	3	10	5	7
12	5	1	2	11	5	13
13	5	3	3	4	3	6
14	6	7	7	14	9	13
15	4	5	7	15	5	16
16	5	3	4	10	5	11
17	2	5	4	10	4	7
18	3	1	2	7	1	9
19	4	4	6	6	4	10
20	11	8	9	15	11	12

TABLE XX

I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-N

(Under 5 Illuminants)

	ILLUMINANT					
	I	II	III	IV	V	V
	ORDER					
Subject	2	3	5	4	1	R
1	6	3	8	5	18	9
2	2				6	1
3	2	4	2	3	5	5
4	6	9	9	8	16	10
5	3	2	1	2	6	2
6	6	7	8	7	19	10
7	4	4	1	3	12	7
8	3	4	3	5	11	6
9		1		1	4	2
10	5	3	2	2	9	4
11	4	1	2	1	6	4
12	2	2	2	2	6	
13	6	4	3	5	10	5
14	4	6	3	3	13	4
15	3	1		2	7	2
16	4	2	5	3	10	5
17	11	7	12	13	21	13
18	3	6	3	3	7	6
19	6	5	5	4	11	6
20	11	9	9	10	5	8

Table XXI gives the number of the one hundred color blind subjects who missed each plate under each illuminant, while Table XXII shows the number of the one hundred normal subjects who missed each plate under each illuminant.

An inspection of Table XXI, for example, will demonstrate that plate 1 is much easier for color blinds under Illuminant I, where only 48 per cent of them miss it.

It is obvious that not all plates will be consistent under the various illuminants for both color blind and normal subjects. Since it is desirable to have plates which are consistent for both groups, some criterion must be utilized. For the time being, the results from Illuminant I may be ignored since a minus-blue light has never been used under ordinary testing conditions.

It is essential that the range of difference for each plate under the four illuminants should be a factor in the selection of the "good" plates. In Table XXI the range of difference for plate 1 would be obtained by subtracting 63 (the lowest number of errors for that plate under the four illuminants) from 86 (the highest number of errors for that same plate under the four illuminants). Therefore the range of difference for plate 1 is 23.

A narrow range, of course, would indicate a good plate.

TABLE XXI

RECAPITULATION OF THE FREQUENCY DISTRIBUTIONS

UNDER EACH ILLUMINANT FOR THE FIVE COLOR BLIND GROUPS

(Original 34 Plates of the I-S Test)

Plate	ILLUMINANT I	II	III	IV	V
1	48	63	73	86	86
2	61	69	78	94	96
3	71	77	84	91	93
4	43	56	66	84	86
5	91	89	97	98	99
6	59	73	77	85	83
7	43	60	73	95	97
8	38	51	62	89	95
9	95	93	98	97	99
10	71	83	90	95	91
11	74	77	81	86	82
12	46	55	64	71	72
13	41	54	69	92	84
14	58	76	75	76	74
15	87	99	99	100	99
16	82	81	91	94	93
17	87	96	99	99	100
18	82	92	90	95	97
19	47	49	60	73	71
20	84	85	91	94	94
21	91	92	92	98	97
22	98	97	99	99	100
23	97	94	98	98	97
24	78	84	84	92	85
25	99	99	98	97	95
26	99	99	100	98	100
27	93	96	99	99	99
28	97	99	99	100	99
29	72	86	90	95	97
30	87	94	95	99	99
31	89	96	94	97	98
32	89	100	99	100	100
33	58	60	63	89	90
34	99	99	100	100	99

TABLE XXII

RECAPITULATION OF THE FREQUENCY DISTRIBUTIONS

UNDER EACH ILLUMINANT FOR THE FIVE NORMAL GROUPS

(Original 34 Plates of the I-S Test)

Plate	ILLUMINANT				
	I	II	III	IV	V
1	2		2	6	3
2	1	5	3	4	8
3				8	8
4					
5	21	22	22	40	62
6		2	1	1	7
7	1		1	2	2
8	2	1	1	2	
9	63	68	71	74	82
10	3	6	5	7	4
11	12	23	20	41	34
12	1			1	1
13	2	1		1	1
14	8	8	7	9	14
15	27	33	37	40	47
16	13	16	13	12	12
17	14	30	30	40	55
18	11	19	20	36	39
19		1			
20		1	2	8	14
21	23	25	29	39	48
22	12	14	12	16	14
23	22	30	30	32	34
24	13	9	15	12	19
25	47	52	58	60	65
26	50	62	52	47	56
27	12	15	9	18	22
28	27	19	18	31	42
29	7	5	9	25	48
30	1			2	3
31	19	25	25	35	40
32	12	25	19	17	26
33	1		1	3	3
34	53	41	40	51	65

In Table XXIII are recorded the range of differences for each plate for color blind and for normal subjects under Illuminants II, III, IV and V. The Color Blind column was derived from Table XXI, whereas the Normal column was derived from Table XXII. It is arbitrary as to what range a plate should have in order to be a "good" plate. However, it was decided that a plate would have to meet the criterion of a range difference of no more than 15 for color blinds and for normals. Plates 6, 9, 10, 14, 15, 16, 20, 22, 23, 24, 25, 26, 27, 30, 31, and 32 meet this standard. Although plate 11 does not quite meet this standard (for the normals), it was decided to retain it, at least temporarily since it seemed to have a high face validity.

TABLE XXIII

RANGE OF DIFFERENCES FOR EACH PLATE

FOR COLOR BLIND AND FOR NORMAL

PLATE	COLOR BLIND	NORMAL
1	23	6
2	27	5
3	24	8
4	40	
5	10	40
6*	12	6
7	37	2
8	44	2
9*	6	14
10*	12	3
11*	9	18
12	17	1
13	38	1
14*	2	7
15*	1	14
16*	13	4
17	4	25
18	7	20
19	22	1
20*	9	13
21	6	23
22*	3	4
23*	4	4
24*	8	10
25*	4	13
26*	2	15
27*	3	13
28	1	24
29	11	43
30*	5	3
31*	4	15
32*	1	8
33	30	3
34	1	24

*Plates selected as good plates on criterion of narrow range.

After the 17 "consistent" plates of the I-S test were selected, error scores were statistically determined on the basis of these 17 plates only.

Tables XXIV through XXXIII give the scores for each subject under the five illuminants. In the last column is recorded the test-retest difference for each subject.

Tables XXIV through XXVIII are concerned with the color blinds whereas Tables XXIX through XXXIII are concerned with the normals.

TABLE XXIV

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	I	II	III	IV	V	I
	ORDER						
Subject	1	R	4	3	2	5	1-R
1	17	16	17	17	17	17	1
2	16	14	15	17	15	14	2
3	17	17	17	17	17	17	
4	16	13	17	16	17	17	3
5	16	15	17	17	17	17	1
6	17	17	17	17	17	17	
7	17	17	17	17	17	17	
8	15	14	17	17	17	15	1
9	14	14	17	17	17	17	
10	16	17	14	16	15	16	-1
11	17	17	17	16	16	15	
12	11	8	12	15	15	15	3
13	16	16	16	17	17	17	
14	17	16	17	17	17	17	1
15	17	16	17	17	17	17	1
16	14	11	13	15	17	15	3
17	15	12	17	17	17	17	3
18	15	15	16	17	17	17	
19	17	17	17	17	17	16	
20	16	13	12	13	12	13	3

TABLE XXV

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	II	III	IV	V	II
	ORDER						
Subject	5	1	R	2	3	4	1-R
1	17	17	17	17	17	17	
2	9	14	11	16	14	16	3
3	9	12	10	12	12	12	2
4	14	16	15	16	15	15	1
5	9	13	7	13	14	16	6
6	10	16	14	17	17	16	2
7	15	15	17	17	17	17	-2
8	16	17	16	16	16	16	1
9	13	13	13	10	14	12	
10	16	16	16	15	15	14	
11	13	17	13	16	17	13	4
12	16	17	17	17	17	17	
13	5	15	13	13	17	15	2
14	14	15	13	15	17	16	2
15	17	17	17	17	17	17	
16	16	17	16	17	16	14	1
17	15	16	15	15	17	17	1
18	16	17	17	16	15	12	
19	16	17	17	17	17	17	
20	16	16	15	17	17	16	1

TABLE XXVI

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	III	IV	V	III
	ORDER						
Subject	4	2	1	R	5	3	1-R
1	13	13	17	15	15	17	2
2	12	14	15	16	17	17	2
3	10	12	16	14	17	17	-1
4	17	17	17	17	17	17	2
5	17	17	17	17	17	15	
6	17	17	17	17	17	17	
7	17	16	17	17	17	17	
8	16	16	16	16	17	17	
9	15	17	17	17	17	17	
10	14	13	12	12	15	13	
11	16	16	16	15	15	15	1
12	16	17	17	17	17	17	
13	17	17	17	17	17	17	
14	15	17	17	15	17	17	2
15	16	17	17	16	17	17	1
16	11	15	15	17	17	17	-2
17	16	17	17	17	17	17	
18	17	17	17	17	16	15	
19	8	13	16	11	15	16	5
20	13	14	16	15	17	16	1

TABLE XXVII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	IV	V	IV
	ORDER						
Subject	3	5	4	1	R	2	1-R
1	17	17	17	17	17	17	
2	15	17	16	16	13	15	3
3	14	17	15	14	15	14	-1
4	12	10	13	13	15	16	-2
5	8	13	13	14	15	14	-1
6	17	14	15	15	16	14	-1
7	13	12	17	15	14	16	1
8	13	12	17	17	16	17	1
9	8	8	10	12	11	14	1
10	16	15	13	14	14	15	
11	10	12	13	14	14	17	
12	10	13	16	17	17	16	
13	12	13	11	12	12	16	
14	16	16	16	16	15	16	1
15	10	17	17	17	17	17	
16	17	17	17	16	15	16	1
17	13	14	13	15	17	17	-2
18	13	12	15	16	17	16	-1
19	17	17	17	17	17	17	
20	13	13	15	17	15	16	2

TABLE XXVIII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-C

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	V	V	V
	ORDER						
Subject	2	3	5	4	1	R	1-R
1	16	16	15	17	16	16	
2	17	17	17	17	17	17	
3	13	12	13	13	16	14	2
4	16	16	17	13	13	13	
5	17	17	16	17	17	17	
6	13	14	14	14	17	17	
7	15	15	16	15	15	15	
8	16	17	16	17	17	17	
9	16	17	16	16	16	16	
10	10	12	15	16	15	17	-2
11	17	16	17	17	15	17	-2
12	12	14	16	17	17	17	
13	17	17	17	17	17	17	
14	13	11	13	17	17	15	2
15	15	17	16	17	17	17	
16	17	17	17	17	17	17	
17	14	16	17	17	17	17	
18	15	14	13	15	17	16	1
19	14	17	17	17	17	17	
20	16	16	17	17	17	17	

TABLE XXIX

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	I	II	III	IV	V	I
	ORDER						
Subject	1	R	4	3	2	5	1-R
1	4	2	3	3	4	3	2
2	4	3	3	2	5	3	1
3	5	4	4	2	2	5	1
4	2	2	1	2	1	1	
5	6	3	3	4	6	5	3
6		1		2			-1
7	2	2	1	2	4	2	
8	4	3	3	5	8	5	1
9	7	6	9	7	10	6	1
10	7	6	4	7	8	7	1
11	8	5	4	4	5	7	3
12	2	1	1	1	5	3	1
13	3	2	2	4	4	3	1
14	4	4	6	6	6	7	
15	2		1		1	1	2
16		1				1	-1
17	2	1		2			1
18	4	2	3	3	3	3	2
19	1	3	3	4	6	6	-2
20	3	3	2	3	4	4	

TABLE XXX

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	II	III	IV	V	II
	ORDER						
Subject	5	1	R	2	3	4	1-R
1	3	3	2	4	5	2	1
2	5	8	5	7	6	7	3
3	4	4	3	4	4	5	1
4		4	1	1	5	4	3
5	2	5	1	2	2	2	4
6	3	3	2	5	5	2	1
7	1	4	1	4	3	3	3
8	6	5	4	6	8	7	1
9	6	11	4	9	4	4	7
10	6	7	4	5	7	11	3
11	2	4	1	4	1	3	3
12	3	6	4	7	3	4	2
13	1	1	1	2	1	2	
14		3					3
15	6	11	5	9	10	12	6
16	2	8	3	5	6	7	5
17		1			1	1	1
18	4	6	4	4	7	6	2
19	1	4		1	2	4	4
20	2	7	5	4	7	6	2

TABLE XXXI

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	III	IV	V	III
	ORDER						
Subject	4	2	1	R	5	3	1-R
1	3	5	6	1	3	5	5
2	5	7	9	6	6	8	3
3	1	3	2	2	4	2	
4	3	9	8	8	4	4	
5	4	7	5	5	6	9	
6	2	5	4	1	1	7	3
7	2	6	5	3	3	7	2
8	3	2	4	2	4	3	2
9		1	5	2	3	4	3
10	6	3	4	2	4	3	2
11			1			1	1
12	5	3	7	4	5	7	3
13	1		2	1	1	3	1
14		2	5	1	6	4	4
15	1	5	3	2	4	6	1
16	2	2	3	3	2	6	
17	4	7	8	7	8	7	1
18	4	5	4	2	4	8	2
19		4	5	1	2	4	4
20	3	7	5	3	8	7	2

TABLE XXXII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	IV	V	IV
	ORDER						
Subject	3	5	4	1	R	2	1-R
1	5	3	5	8	3	7	5
2	5	9	5	8	6	10	2
3	9	8	10	11	8	9	3
4	2	3	6	6	2	5	4
5	1	3	2	5	3	5	2
6	1	1	3	7	3	5	4
7	3	5	4	9	5	7	4
8	2	3	3	3	3	4	
9	4	4	5	6	1	3	5
10	7	4	2	10	3	6	7
11	2	4	2	6	3	5	3
12	3	1	1	5	5	7	
13	4	3	2	3	2	2	1
14	5	5	6	7	6	6	1
15	3	4	5	8	3	9	5
16	4	2	3	5	4	5	1
17	2	5	3	5	3	4	2
18	2	1	2	6	1	6	5
19	2	2	4	3	2	6	1
20	6	5	6	7	7	6	

TABLE XXXIII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-N

(Under 5 Illuminants)

	ILLUMINANT						
	I	II	III	IV	V	V	V
	ORDER						
Subject	2	3	5	4	1	R	1-R
1	5	2	6	3	10	4	6
2	2				4		4
3	2	2	1	3	4	3	1
4	3	6	6	7	10	6	4
5	2	2	1	1	4	2	2
6	5	5	6	6	11	4	7
7	3	3	1	2	7	3	4
8	2	4	2	3	7	5	2
9				1	2	2	
10	4	3	2	2	3	3	
11	2	1	1	1	2	2	
12	1	2	2	2	3		3
13	3	1	1	3	5	2	3
14	2	6	3	3	7	1	6
15	2	1		1	2	1	1
16	2	1	4	2	5	2	3
17	7	6	7	9	14	10	4
18	2	5	2		3	2	1
19	5	4	4	2	6	4	2
20	5	5	6	5	2	4	-2

It will be remembered that according to Figure 1 the complete range of color temperatures taken in actual and typical testing rooms was from 2,600°K to 10,500°K, or 7,900°; also, that the color temperatures of Illuminants II, III, IV and V were 2,000°K, 2,850°K, 6,500°K, and 14,000°K respectively or a range of 12,000°. This range is far greater than found under ordinary conditions (7,900°). Therefore it was deemed feasible to interpolate scores for two new intermediate illuminants for each subject. By this method scores were computed in the following manner. It was assumed that the scores ran in some continuum between Illuminants II through V.

From this it was desirable to compute the most probable score of each subject under the two new intermediate illuminants, one with a color temperature of 2,425°K and the other, 10,250°K. These fall approximately midway between Illuminants II and III, and IV and V respectively. They will be referred to hereinafter as Illuminants II* and V* respectively. While this range (7,825°) is not quite as broad as the actual range (7,900°) and does not include three of the color temperatures (i.e., 1% frequency) that were found above 10,250°K, it will suit our purposes.

The interpolated scores for each individual under these new illuminants was always taken to the nearest whole number and always favoring the illuminant away from the two actual illuminants, III and IV.

For instance, in Table XXXIV, the scores for subject 1 was derived from Table I. His score under Illuminant II* was interpolated from his scores under Illuminants II and III. His score should be 9.5, (between 10 and 9), but since it was decided to interpolate to nearest

whole number away from Illuminant III, it had to be 10.

Tables XXXIV through XLIII show the AO test scores for each individual under the four illuminants.

In Tables XXXIV through XXXVIII are the scores of the color blinds whereas in Tables XXXIX through XLIII are the scores of the normals. In column D of those Tables is listed the range of difference for each subject under these four illuminants.

TABLE XXXIV

AO TEST SCORES OF 20 SUBJECTS IN GROUP I-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	4	3	2	5	D
1	10	9	14	15	6
2	9	12	12	11	3
3	17	18	16	15	3
4	7	6	14	15	9
5	9	9	14	14	5
6	16	16	14	15	2
7	8	8	12	14	6
8	9	10	12	12	3
9	8	7	13	12	6
10	14	14	12	13	2
11	16	16	15	16	1
12	5	6	11	11	6
13	10	11	16	17	7
14	9	9	16	15	7
15	17	16	16	16	1
16	5	5	8	9	4
17	8	8	16	16	8
18	7	8	14	14	7
19	15	14	14	12	3
20	8	10	11	10	3

TABLE XXXV

AO TEST SCORES OF 20 SUBJECTS IN GROUP II-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	1	2	3	4	D
1	10	11	15	16	6
2	3	4	8	10	7
3	1		2	3	3
4	10	10	11	11	1
5	1		5	7	7
6	9	10	14	14	5
7	7	7	11	11	4
8	14	13	13	13	1
9	6	9	9	8	3
10	15	16	15	15	1
11	7	8	10	11	4
12	11	12	16	15	5
13	5	4	12	11	8
14	3	4	6	8	5
15	15	16	16	15	1
16	15	13	13	12	3
17	7	6	10	9	4
18	15	15	14	12	3
19	12	13	14	16	4
20	13	12	15	14	3

TABLE XXXVI

AO TEST SCORES OF 20 SUBJECTS IN GROUP III-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	2	1	5	3	D
1	11	12	17	17	6
2	7	9	10	12	5
3	6	4	4	6	2
4	16	16	14	14	2
5	16	16	16	15	1
6	15	16	15	16	1
7	10	11	15	16	6
8	9	10	14	15	6
9	9	10	14	15	6
10	3	4	4	6	3
11	12	10	9	10	3
12	12	11	12	13	2
13	11	11	16	16	5
14	8	9	16	17	9
15	5	6	7	10	5
16	10	12	15	13	5
17	11	13	16	17	6
18	12	13	13	14	2
19	3	3	9	9	6
20	6	7	10	12	6

TABLE XXXVII

AO TEST SCORES OF 20 SUBJECTS IN GROUP IV-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	5	4	1	2	D
1	17	17	17	16	1
2	16	15	13	13	3
3	12	13	13	14	2
4	4	5	10	9	6
5	5	6	11	10	6
6	14	12	14	13	2
7	1	1	11	12	11
8	12	13	16	15	4
9	5	7	10	10	5
10	10	11	12	11	2
11	1	3	8	9	8
12	6	6	13	12	7
13	4	5	10	10	6
14	16	16	15	14	2
15	7	9	12	15	8
16	14	14	15	14	1
17	6	6	15	13	9
18	6	7	15	13	9
19	8	10	15	16	8
20	4	5	12	11	8

TABLE XXXVIII

AO TEST SCORES OF 20 SUBJECTS IN GROUP V-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	3	5	4	1	D
1	8	9	10	12	4
2	16	17	13	15	4
3	1	2	5	7	6
4	15	16	15	15	1
5	10	12	11	13	3
6	5	6	12	14	8
7	8	10	14	15	7
8	10	10	13	15	5
9	7	7	13	14	7
10	9	9	14	13	5
11	3	3	4	8	5
12	7	8	14	13	7
13	16	15	14	14	2
14	6	6	13	14	8
15	10	11	16	15	6
16	14	16	16	15	2
17	12	17	16	17	5
18	10	9	13	14	5
19	10	11	17	17	7
20	7	9	13	14	7

TABLE XXXIX

AO TEST SCORES OF 20 SUBJECTS IN GROUP I-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	4	3	2	5	D
1					
2					
3					
4					
5				1	1
6					
7				1	1
8					
9				1	1
10			2	1	2
11			1		1
12			1	2	2
13					
14					
15					
16				1	1
17					
18				1	1
19			1		1
20				1	1

TABLE XL

AO TEST SCORES OF 20 SUBJECTS IN GROUP II-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	1	2	3	4	D
1					
2				1	1
3				1	1
4					
5				1	1
6			1		1
7					
8					
9	1		1		1
10				1	1
11					
12					
13				1	1
14					
15	1			1	1
16	1	1		1	1
17					
18					
19					
20				1	1

TABLE XLI

AO TEST SCORES OF 20 SUBJECTS IN GROUP III-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	2	1	5	3	D
1					
2				1	1
3				1	1
4			1	2	2
5					
6					
7				1	1
8					
9				1	1
10				1	1
11					
12					
13					
14					
15				1	1
16				1	1
17		1		1	1
18				1	1
19					
20	1	1	3	4	3

TABLE XLII

AO TEST SCORES OF 20 SUBJECTS IN GROUP IV-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	5	4	1	2	D
1					
2			1	1	1
3					
4					
5					
6			3	2	3
7			1		1
8				1	1
9			1		1
10			1	1	1
11					
12			1		1
13					
14					
15			1	2	2
16			1		1
17					
18			1		1
19					
20			1	2	2

TABLE XLIII

AO TEST SCORES OF 20 SUBJECTS IN GROUP V-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	3	5	4	1	D
1				2	2
2					
3					
4					
5					
6					
7					
8				1	1
9					
10					
11				1	1
12					
13				1	1
14				1	1
15					
16	1	1	3	4	3
17					
18				1	1
19			1	2	2
20				1	1

Tables XLIV through LIII show the 17 plate I-S test scores and the range of difference for each individual under the four illuminants.

Tables XLIV through XLVIII are concerned with the color blinds whereas Tables XLIX through LIII are concerned with normals.

TABLE XLIV

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	4	3	2	5	D
1	17	17	17	17	
2	16	17	15	14	3
3	17	17	17	17	
4	17	16	17	17	1
5	17	17	17	17	
6	17	17	17	17	
7	17	17	17	17	
8	17	17	17	16	1
9	17	17	17	17	
10	15	16	15	16	1
11	17	16	16	15	2
12	13	15	16	15	3
13	16	17	17	17	1
14	17	17	17	17	
15	17	17	17	17	
16	14	15	17	15	3
17	17	17	17	17	
18	16	17	17	17	1
19	17	17	17	16	1
20	12	13	12	13	1

TABLE XLV

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	1	2	3	4	D
1	17	17	17	17	
2	15	16	14	16	2
3	12	12	12	12	
4	16	16	15	15	1
5	13	13	14	15	2
6	16	17	17	16	1
7	16	17	17	17	1
8	17	16	16	16	1
9	12	10	14	13	4
10	16	15	15	14	2
11	17	16	17	15	2
12	17	17	17	17	
13	14	13	17	16	4
14	15	15	17	16	2
15	17	17	17	17	
16	17	17	16	15	2
17	16	15	17	17	2
18	17	16	15	13	4
19	17	17	17	17	
20	16	17	17	16	1

TABLE XLVI

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	2	1	5	3	D
1	15	17	15	17	2
2	14	15	17	17	3
3	14	16	17	17	3
4	17	17	17	17	
5	17	17	17	16	1
6	17	17	17	17	
7	16	17	17	17	1
8	16	16	17	17	1
9	17	17	17	17	
10	13	12	15	14	3
11	16	16	15	15	1
12	17	17	17	17	
13	17	17	17	17	
14	17	17	17	17	
15	17	17	17	17	
16	15	15	17	17	2
17	17	17	17	17	
18	17	17	16	15	2
19	14	16	15	16	2
20	15	16	17	16	2

TABLE XLVII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	5	4	1	2	D
1	17	17	17	17	
2	17	16	16	15	2
3	17	15	14	14	3
4	11	13	13	15	4
5	13	13	14	14	1
6	14	15	15	14	1
7	14	17	15	16	3
8	14	17	17	17	3
9	9	10	12	14	5
10	14	13	14	15	2
11	12	13	14	16	4
12	14	16	17	16	3
13	12	11	12	14	3
14	16	16	16	16	
15	17	17	17	17	
16	17	17	16	16	1
17	14	13	15	16	3
18	13	15	16	16	3
19	17	17	17	17	
20	14	15	17	16	3

TABLE XLVIII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-C

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	3	5	4	1	D
1	16	15	17	16	2
2	17	17	17	17	
3	12	13	13	15	3
4	16	17	13	13	4
5	17	16	17	17	
6	14	14	14	16	2
7	15	16	15	15	1
8	17	16	17	17	1
9	17	16	16	16	1
10	13	15	16	15	3
11	16	17	17	16	1
12	15	16	17	17	2
13	17	17	17	17	
14	12	13	17	17	5
15	17	16	17	17	1
16	17	17	17	17	
17	16	17	17	17	1
18	14	13	15	16	3
19	17	17	17	17	
20	16	17	17	17	1

TABLE XLIX

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP I-N

(Under 4 Illuminants

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	4	3	2	5	D
1	3	3	4	3	1
2	3	2	5	4	3
3	3	2	2	3	1
4	1	2	1	1	1
5	3	4	6	5	3
6	1	2			2
7	1	2	4	3	3
8	4	5	8	6	4
9	8	7	10	8	3
10	5	7	8	7	3
11	4	4	5	6	2
12	1	1	5	4	4
13	3	4	4	3	1
14	6	6	6	7	1
15	1		1	1	1
16				1	1
17	1	2			2
18	3	3	3	3	
19	3	4	6	6	3
20	2	3	4	4	2

TABLE L

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP II-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	1	2	3	4	D
1	3	4	5	3	2
2	8	7	6	7	2
3	4	4	4	5	1
4	3	1	5	4	4
5	4	2	2	2	2
6	4	5	5	4	1
7	4	4	3	3	1
8	5	6	8	7	3
9	10	9	4	4	6
10	6	5	7	9	4
11	4	4	1	2	3
12	6	7	3	4	4
13	1	2	1	2	1
14	2				2
15	10	9	10	11	2
16	7	5	6	7	2
17	1		1	1	1
18	5	4	7	6	3
19	3	1	2	3	2
20	6	4	7	6	3

TABLE LI

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP III-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	2	1	5	3	D
1	5	6	3	4	3
2	8	9	6	7	3
3	3	2	4	3	2
4	9	8	4	4	5
5	6	5	6	8	3
6	5	4	1	4	4
7	6	5	3	5	3
8	3	4	4	3	1
9	3	5	3	4	2
10	3	4	4	3	1
11		1		1	1
12	5	7	5	6	2
13	1	2	1	2	1
14	3	5	6	5	3
15	4	3	4	5	2
16	2	3	2	4	2
17	7	8	8	7	1
18	5	4	4	6	2
19	4	5	2	3	3
20	6	5	8	7	3

TABLE LII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP IV-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	5	4	1	2	D
1	4	5	8	7	4
2	7	5	8	9	4
3	9	10	11	10	2
4	4	6	6	5	2
5	3	2	5	5	3
6	2	3	7	6	5
7	5	4	9	8	5
8	3	3	3	4	1
9	4	5	6	4	2
10	3	2	10	8	8
11	4	3	6	5	3
12	1	1	5	6	5
13	3	2	3	2	1
14	4	6	7	6	2
15	4	5	8	9	5
16	2	3	5	5	3
17	4	3	5	4	2
18	1	2	6	6	5
19	3	4	3	5	2
20	5	6	7	6	2

TABLE LIII

17 PLATE I-S TEST SCORES OF 20 SUBJECTS IN GROUP V-N

(Under 4 Illuminants)

	ILLUMINANT				
	II*	III	IV	V*	
	ORDER				
Subject	3	5	4	1	D
1	4	6	3	7	4
2				2	2
3	2	1	3	4	3
4	6	6	7	9	3
5	2	1	1	3	2
6	5	6	6	9	4
7	2	1	2	5	4
8	3	2	3	5	3
9			1	2	2
10	3	2	2	3	1
11	1	1	1	2	1
12	2	2	2	3	1
13	1	1	3	4	3
14	5	3	3	5	2
15	1		1	2	2
16	2	4	2	4	2
17	6	7	9	12	6
18	4	2		2	4
19	4	4	2	4	2
20	5	6	5	3	3

From column D of Tables XXXIV through LIII were tabulated the frequency distributions of maximum differences of scores of color blind and normal individuals on the AO and on the I-S tests.

These, together with their means and standard deviations, were recorded in Table LIV. An inspection of this table will disclose the following facts: (1) that the I-S test is quite consistent in means and standard deviations between color blind and normal under varying illumination, whereas the AO test is not; (2) that the means and standard deviations for the I-S are smaller; (3) that only 3 percent of the normals and none of the color blind have score deviations on the I-S test of more than 5; whereas none of the normal and 41 percent of the color blind have score deviations of more than 5 on the AO test. These facts prove that the I-S test is an illuminant-stable test, while the AO is not.

TABLE LIV

FREQUENCY DISTRIBUTIONS OF MAXIMUM DIFFERENCES OF SCORES OF COLOR BLIND AND NORMAL INDIVIDUALS ON AO AND I-S TESTS

(Under 4 Illuminants)

Differences	FREQUENCY			
	AO C	AO N	I-S C	I-S N
11	1			
10				
9	4			
8	8			1
7	11			
6	17			2
5	14		2	6
4	8		6	12
3	14	3	17	25
2	12	7	18	31
1	11	41	26	22
0		49	31	1
Number of Subjects	100	100	100	100
Mean	4.7	0.6	1.5	2.7
S.D.	2.4	0.7	1.3	1.4

From column 1-R of Tables I through X, and XXIV through XXXIII were tabulated the frequency distributions of the test-retest differences of individuals for the color blind and the normal on the AO and I-S tests. These were recorded in Table LV together with their means and standard deviations. This should give a measure of the practice effect. Very little practice effect can be noted in any group.

The I-S normals better their scores on the average by only 2.2 points, while all the others change even less.

From this it could be concluded that both the AO and the I-S tests have high reliabilities. This conclusion in regard to the I-S test is justified, because subjects either read the correct number or fail to read any number, unequivocally. But with the AO test frequently the reading is changed from one number to another in such a confusing manner as to make the technique of administration and scoring difficult and uncertain, and to reduce reliability.

TABLE LV

FREQUENCY DISTRIBUTIONS OF TEST-RETEST DIFFERENCES OF INDIVIDUALS FOR COLOR BLIND AND NORMAL ON AO AND I-S TESTS

(Under 5 Illuminants)

Differences	FREQUENCY			
	AO C	AO N	I-S C	I-S N
7				3
6			1	3
5	1		1	6
4	7		1	11
3	7	2	7	17
2	15	4	12	17
1	21	15	19	24
0	26	77	53	15
-1	16	1	6	2
-2	3	1	6	2
-3	4			
Number of Subjects	100	100	100	100
Mean	0.7	0.3	0.6	2.2
S.D.	1.7	0.7	1.4	1.9

In Table LVI are recorded the frequency of incorrect responses for the 100 color blinds and the 100 normals, the discriminatory index and the discriminatory power (r)[11] of each plate of the I-S test. To put this test under the strictest conditions, the lowest number of incorrect responses for color blinds, and the highest number for normals for each plate under each illuminant was used, on the principle that the more diagnostic the test, the more incorrect responses the color blinds should give and the fewer the normals should give.

An r of .18 is significant to the one percent level. It will be noted that the lowest r is .35 (for plate 9) and the highest r is .87 (for plate 30).

Over one-half of the plates have an r of .70 or higher. It will be remembered that this r approximates a biserial correlation coefficient.

From this it can be concluded that each of the plates listed on Table LVI discriminates very significantly between the color blind and the normal.

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[11] Discriminatory index and r taken from F. B. Davis, op. cit.

TABLE LVI

FREQUENCY OF INCORRECT RESPONSES FOR COLOR BLIND AND NORMAL AND THE DISCRIMINATORY POWER OF EACH PLATE ON THE I-S TEST

Plate	Percent of Subjects Missing Plate		Discriminatory Index	r
	Color Blind	Normal		
6	75	4	56	.73
9	95	78	21	.35
10	86	7	61	.77
11	79	41	25	.39
14	75	12	45	.63
15	99	44	58	.75
16	86	15	51	.69
20	88	11	57	.74
22	98	16	72	.83
23	96	33	53	.70
24	84	16	49	.67
25	96	63	35	.52
26	98	57	45	.63
27	97	20	64	.79
30	94	3	80	.87
31	94	38	46	.64
32	99	22	72	.83

Note: An r of .18 is significant to the 1% level of confidence.

In Table LVII are recorded the average percent of color blinds and of normals missing each plate, and the difficulty rank. The color blinds range from an average of 76 (plate 14) to an average of 100 percent (plate 32) missing each plate; the normals range from 1 (plate 30) to 73 percent (plate 9) missing each plate. It can be seen that the relative difficulty of the plates is well distributed.

The most difficult plate has the highest rank. From this table it can be seen that the order, from easiest to most difficult, is 6, 14, 10, 20, 30, 24, 16, 11, 22, 27, 32, 31, 23, 15, 26, 25, and 9. In the absence of other considerations, this order should be followed in testing. But where cheating by pre-learning is to be avoided, some compromise should be made between this order and randomizing the presentation.

TABLE LVII

RELATIVE DIFFICULTY OF EACH PLATE

FOR COLOR BLIND AND FOR NORMAL

Plate	Percent of Subjects Missing Plate		Difficulty Rank
	Color Blind	Normal	
6	80	2	1
9	97	73	17
10	91	6	4
11	82	30	9
14	76	9	2
15	99	39	14
16	91	13	7
20	92	6	4
22	99	14	9
23	97	31	13
24	87	13	6
25	98	59	16
26	99	52	15
27	98	15	9
30	97	1	4
31	96	31	12
32	100	20	11

In Figure II are recorded and graphed the frequency distributions of error scores on the AO and I-S tests for the color blinds and for the normals under Illuminants II*, III, IV, and V*. The mean and standard deviation for each group is recorded below the chart. The broken line to the left gives the distribution of scores for the normals on the AO test, while that on the right gives the distribution of scores for the color blinds on the AO test. The solid line to the left designates the distribution of scores for the normals on the I-S test, while that to the right designates the distribution for the color blinds.

About eight percent of the males and one-tenth of one percent of the females are presumably color defective. In this study all the color blinds were males. Furthermore, most of these were quite badly color defective.

From an unselected population one could expect to find some resemblance to a normal distribution of this trait. Since there are more normals than color blinds in the unselected population, one would expect to find a wider range of scores for the normals than for the color blinds on any test.

An inspection of the chart shows several things. The scores range from 0 through 4 for the normals on the AO test with about 82% making a score of 0. The same individuals range from 0 through 12 on the I-S test. The color blinds have scores ranging from 0 through 18 on the AO test. If 11 were set as the critical score for color blinds on the I-S test, 3 normals would have to be classified as color blind

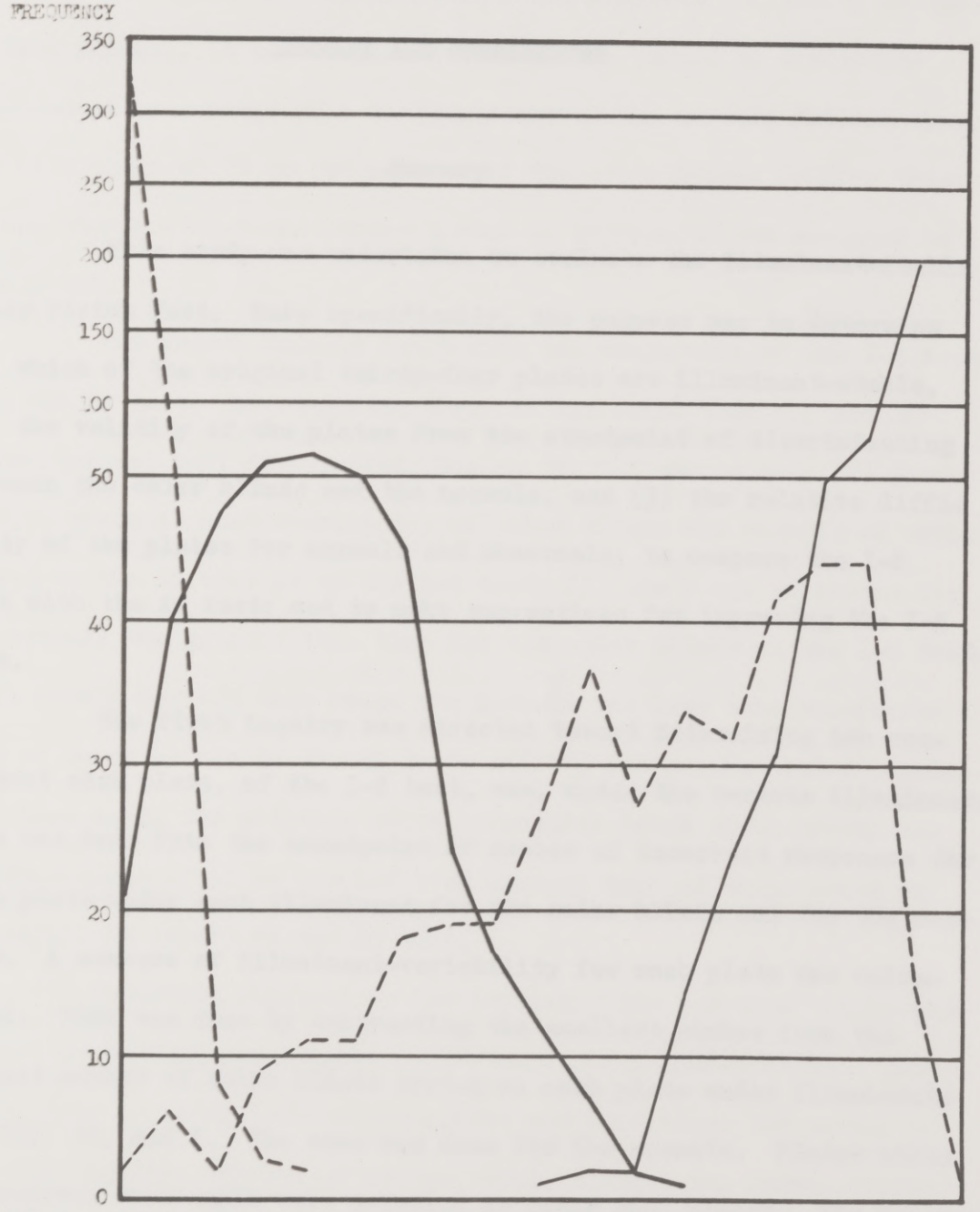
and 3 color blinds as normal. On the AO test, 5 is used as the critical score; thirty color blinds would have to be classified as normal by those standards.

In an unselected population the frequency for the color blinds on the AO and I-S tests would be less than five percent of what is shown on the curves. If a correction were made here, it would be seen that the I-S test scores would be more nearly normally distributed, whereas the AO test scores would nearly all be bunched together at 0. This shows that the AO test is much too easy for the normals and that the normals do not distribute themselves on this test.

It can also be assumed that the means for the color defectives on both tests would have been lowered had a random selection of subjects been used. In that case the results would be much more unfavorable to the AO test than they now are. There would be considerably more color defectives making low error scores, whereas on the I-S test they would distribute themselves close to the "critical score" of 11.

FIGURE II

FREQUENCY DISTRIBUTIONS OF ERROR SCORES ON AO AND I-S TESTS
(FOR COLOR BLIND AND FOR NORMAL)



SCORE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
AO C	2	6	2	9	11	11	18	19	19	27	37	27	34	32	42	44	44	15	1
AO N	329	53	8	3	2														
I-S C										1	2	2	14	24	31	50	79	197	
I-S N	21	40	43	63	67	51	45	26	17	12	7	2	1						

	AO C	AO N	I-S C	I-S N
MEAN	11.2	0.2	15.3	4.1
S.D.	4.0	0.6	2.3	2.4

KEY
AO - - - -
I-S ———

CHAPTER III

SUMMARY AND CONCLUSIONS

Summary

This study was undertaken to evaluate the Illuminant-Stable Color Vision Test. More specifically, the purpose was to determine (1) which of the original thirty-four plates are illuminant-stable, (2) the validity of the plates from the standpoint of discriminating between the color blinds and the normals, and (3) the relative difficulty of the plates for normals and abnormals; to compare the I-S test with the AO test; and to make suggestions for improving the I-S test.

The first inquiry was directed toward determining how consistent each plate, of the I-S test, was, under the various illuminants. This was done from the standpoint of number of incorrect responses for each plate under each illuminant for the color blinds and for the normals. A measure of illuminant-variability for each plate was calculated. This was done by subtracting the smallest number from the largest number of color blinds erring on each plate under Illuminants II, III, IV, and V. The same was done for the normals. Plates whose differences were small were selected as being good plates. The following 17 plates met this criterion, 6, 9, 10, 11, 14, 15, 16, 20, 22, 23, 24, 25, 26, 27, 30, 31, and 32.

The second inquiry was concerned with the internal validity of the plates of the I-S test. It was found that all the 17 plates

cited above had high discriminatory powers.

The third inquiry dealt with the relative difficulty of the various plates. It was found that the plates varied in difficulty represented by a range of 1 to 73 percent of the normals failing them, and by a range of 76 to 100 percent of the color blinds failing them. In accordance with these ranges a rank of difficulty was assigned to each plate.

The fourth inquiry dealt with the comparison of the I-S test with the AO test. By comparing these it was found that (1) the AO scores are not well distributed whereas the I-S scores are; (2) there is five times as much overlapping of color blinds and normals on error scores on the AO test as on the I-S test; (3) the range of scores for the normals was greater than that for the color blinds on the I-S test, as it should be; and that range for normals was less than one-fourth that of color blinds on the AO test; and (4) had an unselected population been used, the slightly color defectives would bunch around the critical score of 11 on the I-S test whereas many of these would be classified as normal on the AO test.

In making suggestions for improving the I-S test little can be said aside from suggestions for bettering the distribution. This can be done by using three-digit plates and increasing the number of two-digit plates. These, of course, would utilize the colors in the most difficult plates of those chosen to be "good" ones.

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Conclusions

From the original 34 plates of the I-S test, the best 17 plates were selected as a revision. In the 17 plate test, (1) each plate meets the condition of illuminant-stability, (2) each plate has a very significant discriminatory power, and (3) the relative difficulty of the plates is well distributed from very easy to fairly difficult for the normals, and from fairly difficult to very difficult for the color blinds.

In comparing the I-S test with the AO test it was found that the I-S test scores were well distributed whereas the AO test scores were not. There was considerably more overlapping between the normals and color blinds on the AO than on the I-S test scores.

It was suggested that the scores on the I-S test would be even more nearly normally distributed by adding some plates that are more difficult for the normals.

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